Indicator Organism Detection in Infiltrates from Permeable Pavement Parking Lots at the Edison Environmental Center, New Jersey

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Abstract

Three types of permeable pavements were monitored at the Edison Environmental Center in Edison, New Jersey for indicator organisms such as fecal coliform, enterococci, and *E. coli*. Results showed that porous asphalt had much lower concentration in monitored infiltrate compared to pervious concrete and permeable interlocking concrete pavers; concentrations of monitored organisms in infiltrate from porous asphalt were consistently below the bathing water quality standard and actually had limited detection. Fecal coliform and enterococci exceeded bathing water quality standards more than 72% and 34% of the time for permeable interlocking concrete pavers and pervious concrete, respectively. Both porous asphalt and pervious concrete had concentration reductions greater than 90% for all three indicator organisms when compared

to runoff values, while permeable interlocking concrete pavers had greater than 90% reduction for *E. coli* only. Neither rain intensity nor temperature was demonstrated to have an observable effect in both concentrations of organisms and performance of permeable pavement; but this may due to the limitations of the dataset consisting of 16 events over an eight-month period.

Key Words: Permeable pavement; indicator organisms; bathing water quality standard; infiltrate; stormwater runoff.

Introduction

Since the inception of the Clean Water Act (CWA) in 1972, the United States has made great efforts in restoring and preserving the physical, chemical, and biological integrity of the nation's waters. However, nearly half of the nation's assessed surface waters remain incapable of maintaining water quality adequate for supporting one or more designated uses, i.e., recreational swimming, fishing, or drinking water supply (USEPA, 2007). National biennial water quality surveys consistently indicate waters are impaired by bacterial indicators, nutrients, sediments, and assorted toxic chemical loadings. A leading cause of this impairment is stormwater runoff from agricultural and urban areas affecting an estimated 9% of impaired rivers and streams, 6% of impaired lake areas, and 12% of impaired estuaries (USEPA, 2009). More river and stream miles were impacted by pathogenic indicator microorganisms than any other pollutant (USEPA, 2009).

Stormwater discharges release pathogenic bacteria, protozoan, and viruses to receiving waters (Pandey et al., 2014). Tata-Maharaj and Scholz (2010) reported typical concentrations in urban runoff as *Escherichia coli* (*E. coli*) ($10^2 - 10^7$ colony forming unit (CFU/100 mL)), fecal streptococci ($10^2 - 10^6$ CFU/100 mL) and fecal coliforms ($10^3 - 10^7$ CFU/100 mL). Selvakumar and Borst (2006) reported concentration ranges for fecal coliforms (5.6×10^3 - 2.2×10^4 CFU/100 mL), enterococci (1.0×10^3 - 6.6×10^3 CFU/100 mL), and *E. coli* (1.5×10^3 - 8.5×10^3 CFU/100 mL) in urban stormwater runoff. Pitt (2011) reported similar nationwide median concentrations for fecal coliform and *E. coli* using data from a number of National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) stormwater permit holders.

Stormwater runoff is commonly treated by stormwater control measures (SCMs), which include wet ponds, wetlands, bioretention areas, dry detention basins, permeable pavements, rain gardens, and proprietary devices. Increasingly, SCMs are being incorporated on-site as low impact development (LID) or as green infrastructure (GI) in the municipal right of way (ROW). Permeable pavement, an alternative to conventional pavement, is a LID/GI infiltration system where the stormwater runoff infiltrates into the ground through a permeable layer of pavement or other stabilized surface reducing the need for runoff drainage and treatment offsite (Field and Sullivan, 2003). Permeable pavement systems can enhance stormwater quality after infiltrating through the system (James and Thompson, 1997; Rushton, 2001; Clausen and Gilbert, 2003; Ellis, *et al*., 2004; Gilbert and Clausen, 2006). There are a variety of permeable pavements and each has unique characteristics that lend themselves to application in specific environments. Permeable pavement usually diverts stormwater runoff into an underground stone reservoir before gradually exfiltrating out of the stone reservoir into the subsoil (Field and Sullivan, 2003) though there are also systems that have a limited storage reservoir for various reasons (e.g., high groundwater, significant underground infrastructure) that discharge to the nearest conveyance system or surface water.

Although many SCMs have been studied for removal of microorganisms, there are limited studies on the effectiveness of porous pavements (Hathaway and Hunt, 2012; Hathaway et al., 2009). Tata-Maharaj and Scholz (2010) found that permeable pavement was effective in removing microorganisms such as total coliforms, *E. coli*, and fecal streptococci by 98-99%. Similarly, few studies have assessed the effectiveness of SCMs on the seasonal removal of microorganisms (Hathaway and Hunt, 2012). Li and Davis (2009) observed the highest *E. coli* and fecal coliform concentrations in the runoff during the summer though SCM removal efficiency was not correlated to the temperature. Tata-Maharaj and Scholz (2010) found that the rates of microbiological degradation were not negatively affected by temperature variations due to seasonal changes.

Fecal indicator microorganisms are found in feces from both human sources (e.g. sewer discharges, and failing septic systems) and nonhuman sources (e.g. pets, waterfowl, and farm animals) (Whitlock, *et al*., 2002). Indicator microorganisms are used to test surface waters as they serve as a proxy for harmful pathogens and also it is difficult to measure the pathogens themselves. These species may not be harmful to human themselves, however, their presence can indicate fecal contamination. Indicator microorganisms tested by public health agencies include total coliform, fecal coliform, fecal streptococci, *E. coli,* and enterococci. The concentrations of these indicators are used to determine the potential for fecal contamination and to compare to public health-based thresholds.

In 1976, the U.S. Environmental Protection Agency's (EPA) recommended that states adopt a bathing water quality standard (BWQS) of fecal coliforms not to exceed 200 organisms/100 mL (USEPA, 1976). In 1986, based on statistical analysis, the USEPA recommended that states revise the recreational water quality microbial criteria to use enterococci for marine waters and *E. coli* or enterococci for freshwaters as *E. coli* and enterococci are more representative of warm blooded animal fecal contamination in water than total or fecal coliforms. Suggested criteria are 35 enterococci per 100 mL for marine waters and 33 enterococci per 100 mL and 126 *E. coli per* 100 mL for freshwaters (USEPA, 1986).

The objectives of this study were to: 1) evaluate the performance of permeable pavement in removing indicator organisms such as fecal coliform, enterococci and *E. coli* from infiltrating stormwater runoff; and 2) potentially evaluate seasonal effects and rainfall intensity on infiltrate concentrations of indicator organisms.

Methods

The EPA's Office of Research and Development operates the Urban Watershed Research Facility (UWRF) at the Edison Environmental Center (EEC) in Edison, New Jersey. The UWRF serves as a location to perform both laboratory-scale and field-scale studies to test monitoring methods and performance of SCMs. The UWRF allows EPA to better understand SCM performance and monitoring methods with a high level of control over external factors. At the EEC in 2009, the U.S. EPA constructed a functional, 0.4 ha, 110-space parking lot that is surfaced with three different permeable pavement types: permeable interlocking concrete pavers (PICP), pervious concrete (PC), and porous asphalt (PA). The site, depicted in Figure 1, was opened for use in October 2009 and it is used daily by EEC staff and visitors.

The three head-to-head parking rows with permeable pavement systems are 11.58 m wide by 42.67 m long while the 7.62 m wide travel lanes are paved with traditional impervious hot mix asphalt. There is a 1.6% surface slope so that each permeable surface receives runoff from the adjacent travel lanes to the north. All surfaces were constructed over an open-graded subbase reservoir of recycled concrete aggregate (RCA) crushed on site to the size of American Association of State Highway and Transportation Officials (AASHTO) No. 2 size aggregate. Five sections of each permeable pavement system allow water to infiltrate into the underlying soil while four of the sections have an impermeable liner 40 cm below each permeable surface which allows infiltrate to be collected for measurement and sampling. The thickness of each permeable surface varies depending on structural needs for that particular application. The PA is 8 cm thick and PC is 15 cm thick. The individual pavers are 9 cm thick and were placed on a 5 cm layer of AASHTO No. 8 aggregate which also filled spaces between pavers; an additional 10 cm layer of AASHTO No. 57 aggregate separated the AASHTO No. 8 and common RCA aggregate for PICP. The infiltration capacity of all three surfaces is very large; the infiltration rate of PC was approximately twice that of PICP. PICP and PC had infiltration rates that were more than one order of magnitude larger than PA. Although the surface infiltration rates vary by more than an order of magnitude, each is much larger than the reasonably expected rain event (USEPA, 2010; Brown and Borst, 2014). A more detailed description of the liners, permeable surfaces and drainage piping is provided in Brown and Borst (2014).

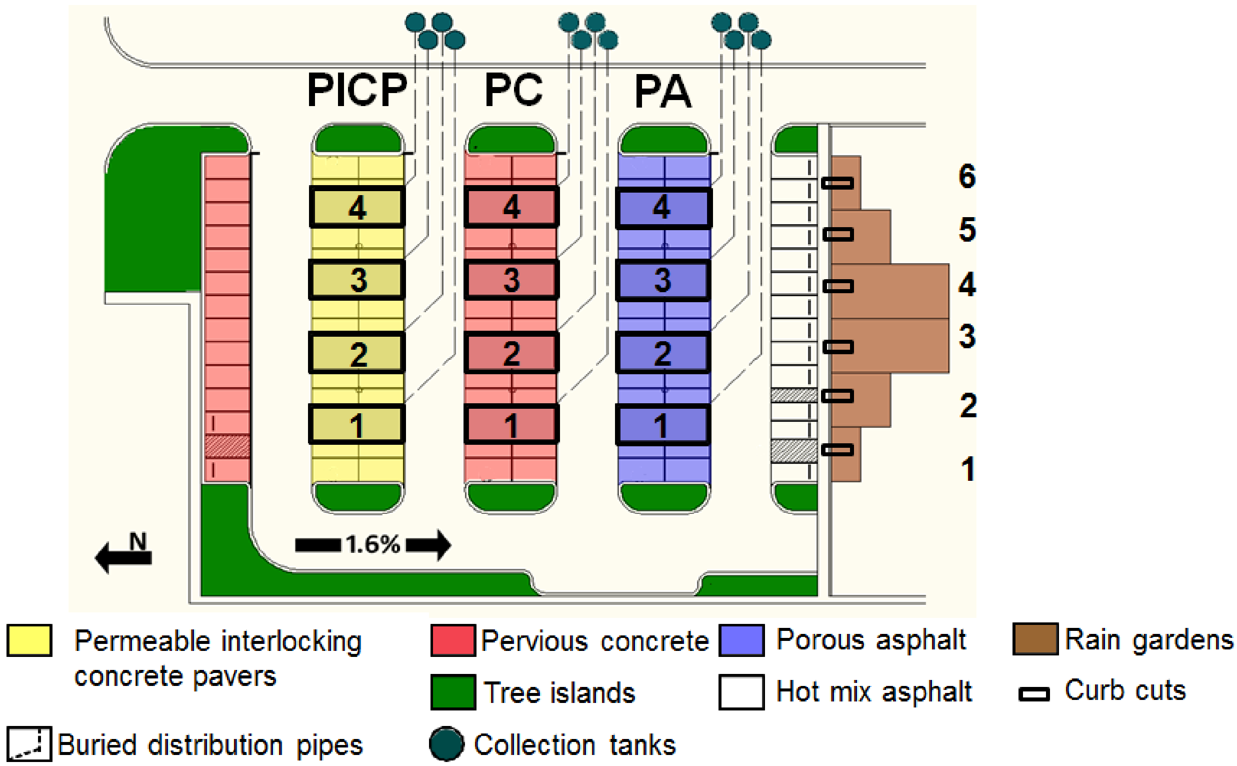


Figure 1. Plan View of Parking Lot

Flow-weighted samples were collected using programmable automatic samplers. Samples were collected from the drainage pipes for collection tanks for permeable surfaces 1 and 3 (see Figure 1) for each permeable surface. Surface Runoff samples were also collected at two curb cuts (CC) (4 and 5 rain gardens) at the south end of the parking lot that collects runoff from impermeable asphalt surface. Details of the overall water quality sampling efforts were described in Borst and Brown (2014).

Sixteen sampling events were conducted between July 2015 and February 2016. Collected samples were transported to the UWRF laboratory and analyses were initiated within the standard holding time of 6 hours. Samples were analyzed for indicator microorganisms such as fecal coliform, enterococci, and *E. coli*. Fecal coliform and *E. coli* were enumerated using Colilert and enterococci was enumerated using Enterolert (IDEXX Laboratories, Inc., Westbrook, Maine). Colilert® and Enterolert® are commercially available enzyme-substrate liquid-broth mediums (IDEXX Laboratories, Inc., Westbrook, Maine). All enumerations were performed using Quanti-tray 2000 trays, which use a most probable number (MPN) based protocol with a quantitation range from less than 1 colony forming unit (cfu)/100 mL to 2,419.6 cfu/100 mL without sample dilution. Each sample was analyzed with and without dilution; infiltrate was analyzed at ten times dilution (observable range of 10 to 24,196 cfu/100 mL) and runoff samples were analyzed at 20 times dilution (observable range 20 to 48,392 cfu/100 mL). Results were reported as the average of the undiluted and diluted analysis. When observed concentrations were below detection limit for both the undiluted and diluted analysis, the value zero was used as the sample concentration as no organisms were present.

Rainfall was measured using a 0.1 mm tipping bucket rain gauge and recorded with a Campbell Scientific CR1000 data logger set to record at 10 minute intervals. The tipping bucket rain gauge is located in the field adjacent to the collection tanks to the east of the parking lot. All storms had at least 2.54 mm (0.1 in.) of rainfall as per NPDES guidance (USEPA, 1992). Air temperature was measured at the UWRF weather station.

Statistical analysis was conducted to evaluate the performance of permeable pavement parking lots in treating stormwater infiltrate. Summary statistics (e.g., means, medians, standard deviations, etc.) were performed in Excel. Because there were non-detects and the percentage of non-detects was below 50 % of the total number of analysis, Atchison's Method (USEPA, 2000) was used to calculate mean and standard deviation. Atchison's method adjusts the mean and standard deviation by assuming that non-detects are actually zero, which is the case as described above.

Normality of data sets were tested by the Shapiro-Wilk W test using Satistica 10 (StatSoft, 2011). A nonparametric Wilcoxon Matched Pair Test (StatSoft, 2011) was used to determine concentration differences between and within permeable surfaces; nonparametric methods can reduce the influence of outliers such as non-detects and values greater than MRL. A statistical significance value of $p \leq 0.05$ was used for all statistical analysis. Box and whisker plots were created to display the data with median as the center point and 25% and 75% as quartiles.

Probability plots were developed in Excel spreadsheets (Microsoft, 2013) to evaluate the performance of different permeable surfaces. Probability was calculated using the following equation (Burton and Pitt, 2002):

$$p = \frac{i - 0.5}{n}$$

where, p = probability of given observation; i = rank of observation within group n; and n = total number of observations within a given data set. These probability values (ordinate) were then plotted against organism concentrations (abscissa) and compared against a vertical straight line representing the BWQS (freshwater criteria, if applicable) for respective microorganisms to demonstrate exceedance occurances.

Treatment by infiltration through the pavement surfaces was determined by calculating percent removal of infiltrate concentration of each surface in comparison to common driving lane surface runoff values collected at the curb cuts. A nonparametric Wilcoxon Matched Pair Test (StatSoft, 2011) was used to determine statistical significance of the differences between driving lane surface runoff and permeable surface infiltrate concentrations.

A least squares log normal regression analysis was performed on rainfall and temperature in comparison to microbial indicator organism concentrations.

Results and Discussion

Summary statistics for the sampling events are presented in Table 1 and Box and Whisker plots are shown in Figure 2. Fecal coliform was detected in infiltrates from both PICP and PC; it was only detected once in PA. The mean fecal coliform concentration in the runoff (represented by CC for curb cuts in Figure 2) was 5,054 MPN/100 mL. The mean fecal coliform concentrations in infiltrates from PICP, PC, and PA were 1911, 177, and 21 MPN/100 mL, respectively; the mean for PICP infiltrate exceeded the BWQS of 200 MPN/100 mL. The concentrations of PICP and PC infiltrate were log normally distributed over the 16 events. Concentrations of fecal coliform in the infiltrate of PICP were always higher than that of PC and PA. The mean fecal coliform concentration in the roof runoff (represented by DB) was 1,148 MPN/100 mL.

Table 1. Summary Statistics of Indicator Organisms for Monitored Storm Events

Sampling Location	Statistics	Fecal Coliform	Enterococci	*E. coli*
Permeable Interlocking Concrete Pavers (PICP)	Detection Frequency (%)	94	100	81
	Mean (MPN/100 mL)	**1,911**[a]	**212**[a]	49
	Median (MPN/100 mL)	1,065	171	8
	Maximum (MPN/100 mL)	8,665	578	344
	Minimum (MPN/100 mL)	<1	5	<1
	Standard Deviation (MPN/100 mL)	2,289	191	104
Porous Concrete (PC)	Detection Frequency (%)	100	100	50
	Mean (MPN/100 mL)	177	**72**[a]	2
	Median (MPN/100 mL)	58	30	1
	Maximum (MPN/100 mL)	692	338	7
	Minimum (MPN/100 mL)	3	1	<1
	Standard Deviation (MPN/100 mL)	232	96	3
Porous Asphalt (PA))	Detection Frequency (%)	6	87.5	0
	Mean (MPN/100 mL)	21	9	<1
	Median (MPN/100 mL)	<1	3	<1
	Maximum (MPN/100 mL)	331	39	<1
	Minimum (MPN/100 mL)	<1	<1	<1
	Standard Deviation (MPN/100 mL)	NA	12	NA
Driving Lane Surface Runoff (CC)	Detection Frequency (%)	88	100	75
	Mean (MPN/100 mL)	**5,054**[a]	**1,070**[a]	**1,315**[a]
	Median (MPN/100 mL)	2,254	37	6
	Maximum (MPN/100 mL)	24,196	12,243	12,141
	Minimum (MPN/100 mL)	<1	2	<1
	Standard Deviation (MPN/100 mL)	8,118	3,076	3,604

[a] Mean concentration exceeds BWQS (bolded).

The mean enterococci concentration in the runoff was 1,070 MPN/100 mL. The enterococci were detected 100% of the time for PICP and PC and was the most prominent detection for PA at 87.5% of events though the PA detection were very low in comparison to PICP and PC. The mean enterococci count in infiltrates from PICP, PC, and PA were 212, 72, and 9 MPN/100 mL, respectively with PICP and PC means exceeding BWQS of 33 MPN/100 mL. The mean enterococci concentration in the roof runoff was 77 MPN/100 mL.

E. coli was detected in PICP during 81% of the events. It was detected in only 50% of the events in PC and at concentrations lower than the PICP. The mean *E. coli* concentrations in infiltrates from PICP and PC were 49 and 2 MPN/100 mL, respectively, while *E. coli* was not detected in PA. The average mean concentration in the runoff was 1,315 MPN/100 mL. The average mean concentration in the roof runoff was 2 MPN/100 mL.

The pH of infiltrate from PC and PICP is normally well above 7, however pH of infiltrate from PA was consistently as high as 11 (O'Connor and Borst, 2016) which may explain why microorganism concentrations in the infiltrate from PA are low or non-existent compared to the other two surfaces. It is planned to conduct a bench-scale study to confirm the effect of pH.

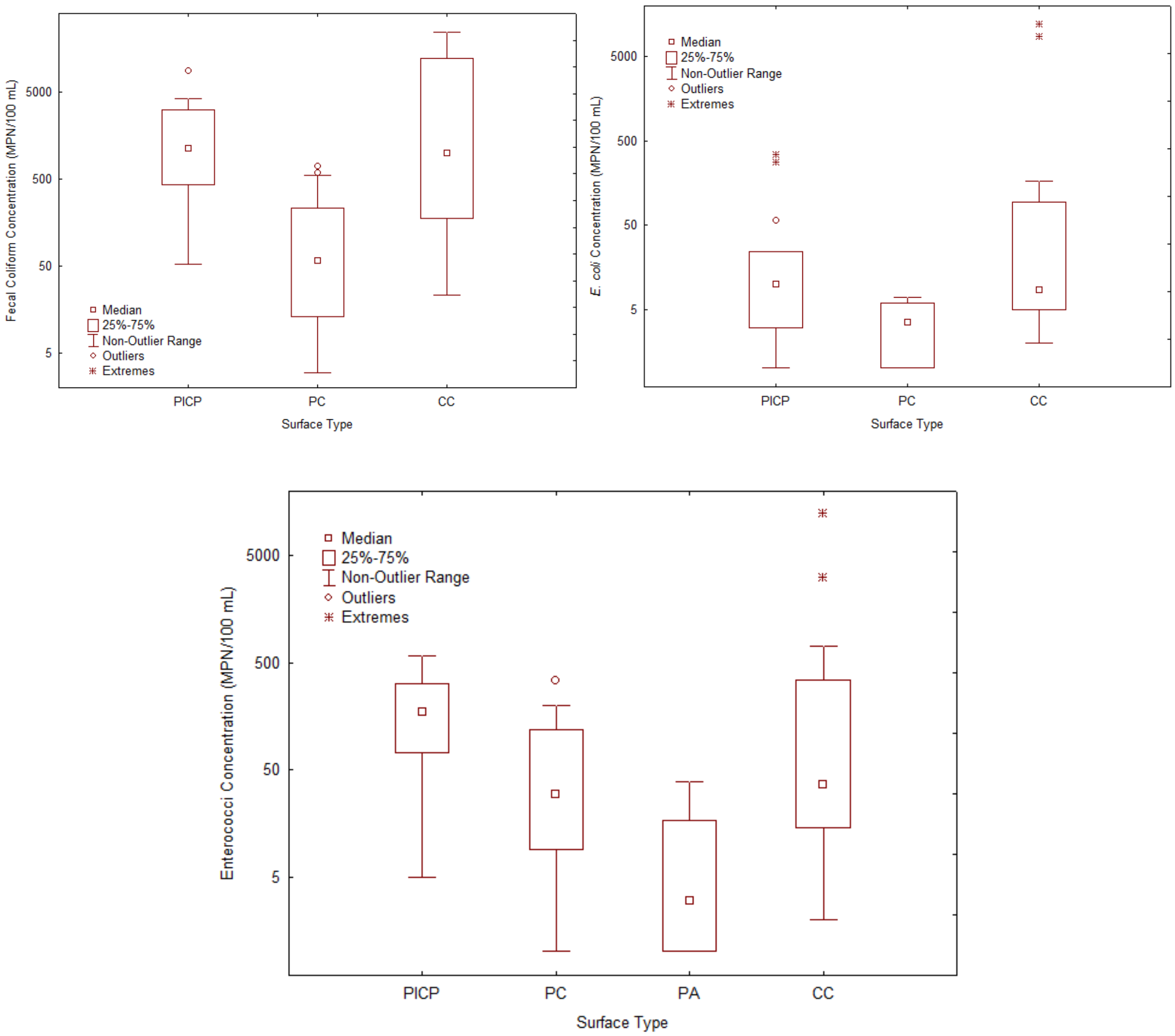


Figure 2. Box and Whisker Plots for Permeable Surface Infiltrate Concentrations

Wilcoxon Matched Pair Test (StatSoft, 2011) indicated there was a statistically significant difference within surfaces for PICP and PC for fecal coliform as shown in Table 2. There was no statistically significant difference within surfaces for enterococci and *E. coli* (Table 2). There is statistically significant difference between all three surfaces ($p < 0.05$) (Table 3) for all three microorganisms.

Table 2. Indicator Organism Concentration Differences within Surfaces

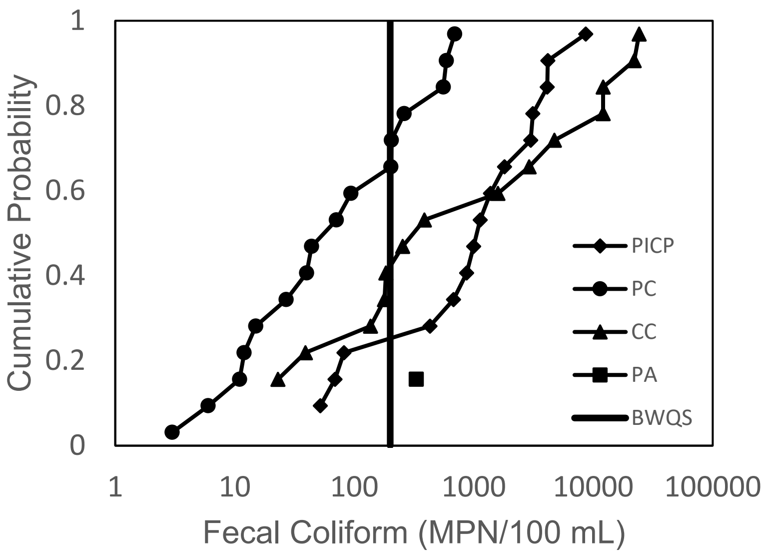
Pavement Types	Fecal Coliform		*Enterococci*		*E. coli*	
	p-value	Statistical Significance	*p*-value	Statistical Significance	*p*-value	Statistical Significance
PICP-1 vs. PICP-3	**0.0007**	Yes	0.121	No	0.15	No
PC-1 vs. PC-3	**0.007**	Yes	0.078	No	1.0	No

Table 3. Indicator Organism Concentration Differences between Surfaces

Pavement Types	Fecal Coliform		Enterococci		*E. coli*	
	p-value	Statistical Significance	*p*-value	Statistical Significance	*p*-value	Statistical Significance
PICP vs. PC	**0.0027**	Yes	**0.0007**	Yes	**0.0047**	Yes
PICP vs. PA	**0.0007**	Yes	**0.0004**	Yes	**0.0015**	Yes
PC vs. PA	**0.0004**	Yes	**0.0024**	Yes	**0.0117**	Yes

Exceedance of Bathing Water Quality Standards

Probability of exceedance of USEPA BWQS are shown in Figure 3 with the vertical line representing the respective BWQS for each microorganism. The probability of exceedance is where the curve crossed the BWQS. The BWQS of 200 MPN/100 mL for fecal coliform was exceeded 72% and 34% of the time for PICP and PC, respectively. BWQS for enterococci was exceeded 78% and 47% for PICP and PC, respectively. BWQS of 126/100 mL for *E. coli* was exceeded only 9% times for PICP.



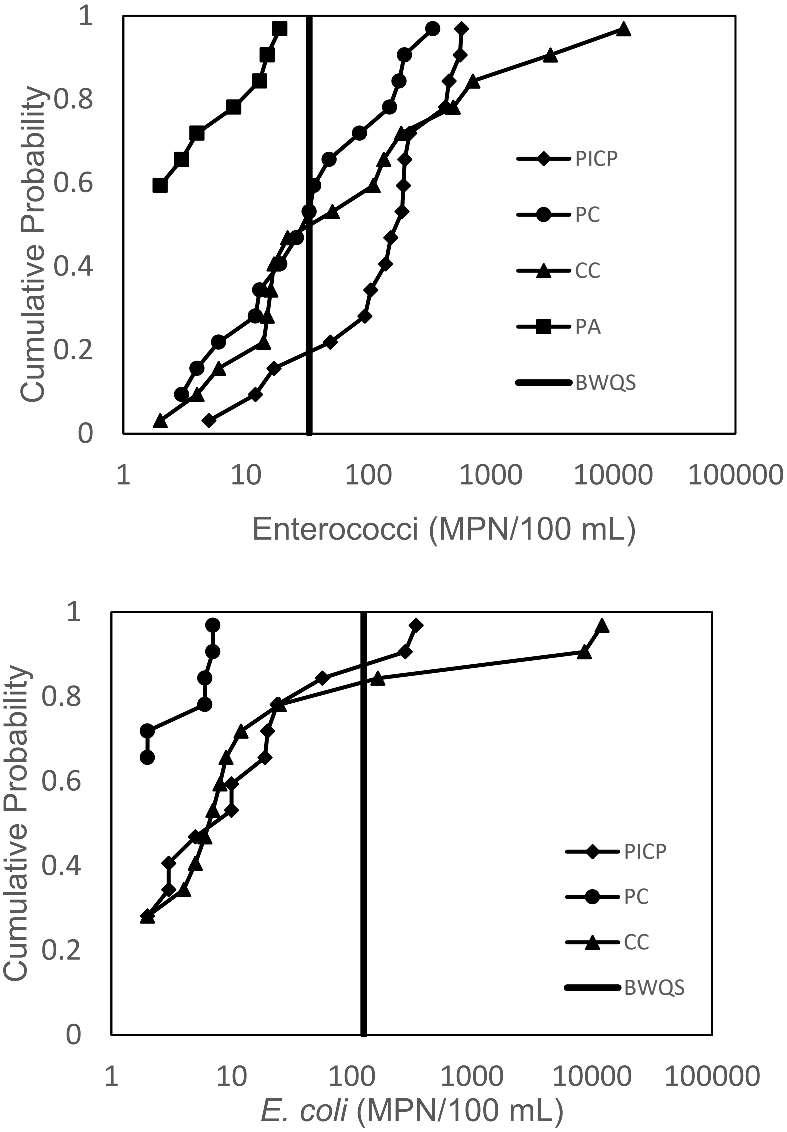


Figure 3. Cumulative Probability Plots of Indicator Organisms

Potential Reduction in Concentration of Indicator Organisms

Estimated concentration reductions of microorganisms for each permeable pavement type in comparison to the common driving lane surface runoff collected at the rain garden curb cuts is documented in Table 4. Concentration reductions of greater than 90% were observed with the exception of fecal coliform (62%) and enterococci (80%) in PICP infiltrate. The highest reduction was observed in PA for all three organisms.

Table 4. Indicator Organism Concentrations Reduction for Permeable Parking Surfaces

Organism	Surface Type	Concentration Reduction (%)
Fecal Coliform	PICP	62.2
	PC	**96.5**
	PA	**99.6**
Enterococci	PICP	80.1
	PC	**93.3**
	PA	**99.6**
E. coli	PICP	**96.3**
	PC	**99.9**
	PA	**100**

Results of Wilcoxon Matched Pair Test are shown in Table 5. PA significantly reduced the concentration of all three organisms ($p \leq 0.05$), whereas PC reduced fecal coliform and *E. coli*. PICP did not significantly reduce any of the organisms. Statistical analyses agreed with the concentration reductions listed in Table 4 except for *E. coli* in PICP.

Table 5. Results of Wilcoxon Matched Pair Test

Surface Type	Fecal Coliform		Enterococci		*E. coli*	
	p-value	Statistical Significance	*p*-value	Statistical Significance	*p*-value	Statistical Significance
PICP	0.3066	No	0.4228	No	0.9770	No
PC	0.0151	**Yes**	0.5180	No	0.0063	**Yes**
PA	0.0009	**Yes**	0.0110	**Yes**	0.0022	**Yes**

Effects of Weather

Between July 2015 and February 2016, 16 sampling events were conducted which equates to two events per month. Rain size ranged from 3.4 mm to 39.4 mm with the mean size of 18.6 mm and median size of 19.7 mm. Rain size is normally distributed as shown in Figure 4. Least-square log normal regression analysis of rain intensity and indicator organism concentrations for all the surfaces had low coefficient of determination ($R^2 \leq 0.33$), which agrees with findings by other researchers (McCarthy *et al*., 2007; Hathaway *et al*., 2010).

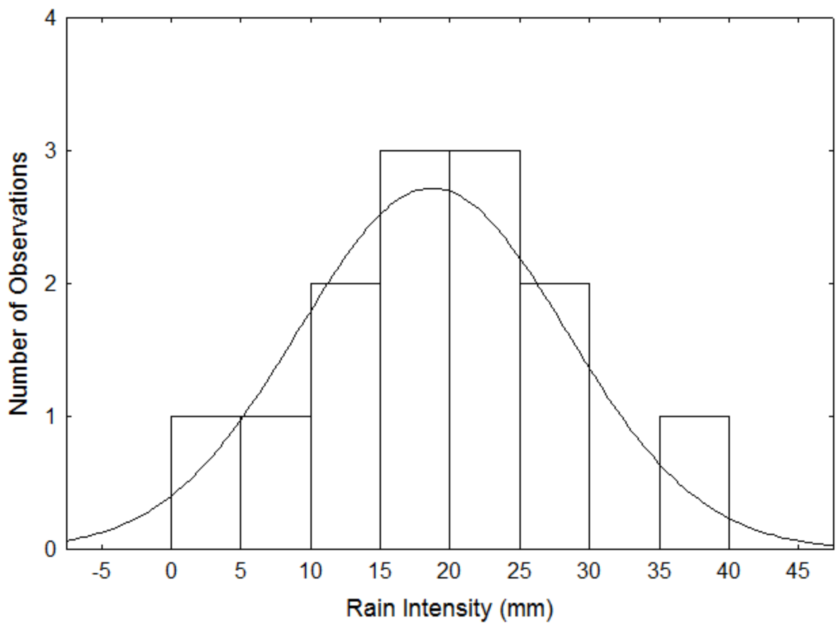


Figure 4. Rain Intensity Distribution of Events Sampled

Event temperatures ranged from -1.07 to 26.35ºC with a mean of 15ºC and median of 13.58ºC (Figure 5). Least-squares log normal regression analysis of temperature and indicator organism concentrations for all three surfaces had low coefficient of determinations ($R^2 \leq 0.20$).

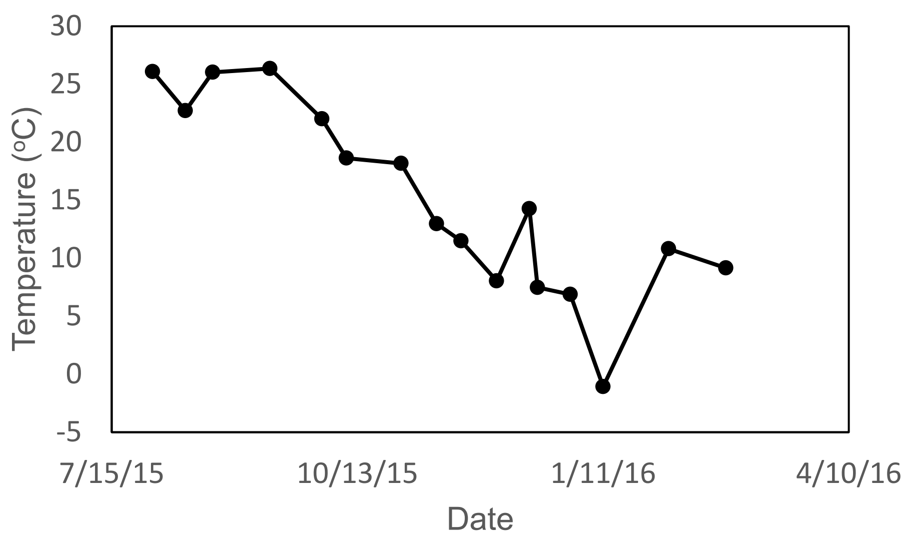


Figure 5. Mean Temperature on Event Days

Conclusion

Porous pavements function as infiltration SCMs, with stormwater runoff passing through the permeable surface where pollutants are removed and storage gallery. Our research suggests that, of the three pavement types tested, porous asphalt consistently had the lowest concentration of indicator microorganisms' load and the concentrations of organisms in the infiltrate water were below the bathing water quality standards. There was a statistically significant difference between all three surfaces for all three organisms with PICP having the highest observed concentrations and frequency of detection.

As expected, impervious driving lane runoff mean concentrations exceed BWQS for all microbial indicators. Concentration reductions of greater than 90% were observed with the exception of fecal coliform (62%) and enterococci (80%) in PICP infiltrate. Results of the probability plots (Figure 3), estimated percent removals (Table 4), and Wilcoxon Matched Pair Test (Table 5) show consistently that permeable asphalt had large reductions of indicator microorganism concentrations. PICP being the most prone to not to reduce concentrations significantly and to have mean concentrations exceeding BWQS for fecal coliform and enterococci.

Despite PA having the shortest profile of 8 cm above the common gallery of RCA, it had the lowest observed concentration of indicator bacteria, while PICP with a total profile depth of 24 cm above the RCA had the highest concentrations. The large pore space of the PICP would appear to let the bacteria through with the infiltrate water while the PA reductions of indicator bacteria may have been assisted by the high observed pH in the infiltrate and possibly organic nature of the asphalt. The PC with 15 cm profile depth had removal performance between these two extremes.

Rain intensity and temperature did not appear to have any effect on either concentration of organisms or the performance of permeable pavement in this small data set; this observation should be confirmed with a larger data set.

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